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Evaluation of Ambient Air Quality and Health Risk Awareness in Vulnerable Workplaces of Pokhara City, Nepal

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ABSTRACT

The ambient air pollution in workplaces poses adverse effects on the health of individuals, which in turn directly affects the competence of the workers and overall productivity. Rapid urbanization, vehicle emissions, factory exhausts, cooking, and the burning of agricultural and domestic waste in growing cities are the major contributors to air pollution, which is harming the health of occupants. The purpose of this study is to assess the levels of particulate matter, the degree of awareness, preventive measures, and the health status of workers at the vulnerable workplaces in Pokhara, Nepal. We assessed the concentration of particulate matter in workstations using a portable pollution meter and carried out a detailed survey with the employees during the peak pollution season in April 2024. The results reveal that the average $PM_{2.5}$ level at the sampling site (201.4 µg/m³) significantly exceeds the safe pollution threshold of annual average 35 µg/m³ and 24-hour average of 75 µg/m³ set by the World Health Organization (WHO) whereas the interim target is to reduce to 25 µg/m³ annually and 50 µg/m³ daily average. A comprehensive survey conducted at 10 randomly selected sites revealed that most workers are engaged without sufficient awareness, precautionary measures, health care services, or emergency requirements. The findings of this study highlight the necessity for public awareness and

consolidate the importance of communal efforts to endorse a safe environment and healthy working conditions for sustainable urban development.

KEYWORDS: Air quality, occupational safety, particulate matter, personal safety, public awareness

INTRODUCTION

Pollution of ambient air by natural as well as anthropogenic sources has become a major threat to the health of people, plants, and animals. Exposure to $PM_{2.5}$ has profound implications for public health, particularly in rapidly urbanizing areas like Pokhara. Fine particulate matter can penetrate deep into the respiratory system, leading to adverse health outcomes such as cardiovascular diseases, respiratory infections, and even premature mortality. The pervasive nature of $PM_{2.5}$ in urban environments is primarily attributed to anthropogenic activities, including vehicular emissions, forest fire, burning of solid waste and construction dust, which are common in densely populated regions. Noise pollution levels in metropolitan areas are frequently correlated with traffic density, as the study mentioned in Khadka (2024) shows. As a result, a similar pattern might be expected for PM 2.5 concentrations, which would increase health risks. Moreover, the increasing severity of climate hazards, as discussed in (Amadio et al., 2022), further complicates the health landscape by potentially intensifying the sources of $PM_{2.5}$, making it imperative for public health strategies to address both emission controls and health monitoring in vulnerable populations. Regmi et al. (2021) reported the trend of declining air quality due to suspended dust particles and aerosols in the Pokhara city. It is anticipated that by 2050, the number of premature deaths due to air pollution could double, making it the most challenging environmental burden to the world (Bhat et al., 2021). The World Health Organization (WHO) estimates that approximately 7 million premature deaths per year are associated to the indoor and outdoor air pollution. Only by reducing the level of air pollution, a significant portion of deaths caused by acute respiratory infections (43%), chronic obstructive pulmonary disease (33%) heart disease (31%), strokes (25%), and lung cancer (20%) could be prevented (World Health Organization, 2024). In urban areas, the major sources of air pollution include vehicle emissions, industrial effluent, combustion of fossil fuels and biomass. This was clearly established by the significant drop in air pollution levels during the COVID-19, when anthropogenic activities were substantially declined on a global scale (Pushpawela et al., 2023). An investigation by Sharma et al. (2020), showed the reduction in the concentrations of PM_{10}, $PM_{2.5,}$ NO_2, CO, O_3, and SO_2, in the 22 cities of India by 43%, 31%, 10%, 18%, and 17% respectively and negligible changes observed for SO_2 during the lockdown period. With the development of metropolitan areas, extension of impermeable surfaces has modified physical properties such as albedo, thermal inertia, and surface roughness. These changes have affected natural processes like water, energy, and momentum, ultimately affecting the air quality in urban areas (Zhan et al., 2023).

In developing countries like Nepal, the increase in number of internal combustion vehicles, industrial emissions, along with inadequate public awareness and lack of stringent rules, has led to the deterioration of air quality. Additionally, air pollution is caused by factors such as the topography, landscapes, climate, the barrier created by high mountains in the north, and the structure of the atmosphere (Das et al., 2018). Increasing mass of waste materials produced from household and industrial activities, excessive use of plastics and package materials, poor sanitation are also contributing air pollution in cities. The Himalayan Tibetan Plateau, often called the "water tower of Asia," is the largest and most widespread mountain range, serving as a site for the deposition of transboundary air pollutants. The southern slope is particularly affected by various human activities leading to air pollution (Dangi et al., 2011; Paudel et al., 2024). Road dust in urban areas contains a mixture of vehicle exhaust, circular, columnar, and irregular particles, as well as soot aggregates, construction materials, and sand particles containing heavy metals. These components have intricate chemical compositions and diverse physical structures and morphologies (Gupta et al., 2022).

Nepal faced a significant flow of rural-to-urban migration during last three decades due to social and political instability. People left villages for cities in search of security, education, employment, and better opportunities. This large-scale population shift resulted in the unplanned and rapid expansion of urban areas (Bhattarai et al., 2023). The lack of proper planning and infrastructure, such as connectivity networks, community centers, healthcare facilities, senior care stations and kid zones, etc., has resulted in poor waste management, water supply, and emergency provisions. The condition is responsible to the disasters like droughts, forest fires, down pouring, floods, and landslides all contributing to increased level of pollution. Pokhara is facing a rural-to-urban migration, with people settling in potential agricultural areas, invading riverbanks, and forest edges. This has led to the expansion of several slums and shantytowns where residents live in poor, uneducated and polluted environments (Bhattarai & Chandra, 2021).

In recent years, researchers have been increasingly focused on urban air quality and its health effects due to issues like population growth, industrialization, challenges of waste management, and climate change, all of which threaten vital natural resources (Deshmukh et al., 2012). Current literature provides limited information on the detailed chemistry of aerosols in the Himalayan foothills, the impact of human activities releasing air pollutants, the formation of secondary pollutants, and the melting and freezing cycles of ice bodies, all contributing to changes in weather pattern and climate. These disturbances to the natural ecosystem result in unusual effects on plant and animal life, including humans. Most of the studies on air pollution and their implications are concentrated to Kathmandu which is regarded as one of the highly polluted city in the world (Saud & Paudel, 2018).

In big cities, health of outdoor employees specially working in informal sectors is adversely affected by the exposure to the environment and harsh weather conditions. Employees involved in the sectors such as auto rickshaw drivers, sweepers, painters, auto mechanic, traffic police, hotel/restaurants cook, metal workers, abattoir staffs, chemical and pharmaceutical lab workers, green groceries, construction workers, etc. are exposed to several occupational risks of road dust, vehicular exhaust, industrial fumes etc. (Bari et al., 2022). In this study, we aimed to assess knowledge and public awareness of air pollution, along with the working conditions and characteristics of dust particles and particulate matter in some of the vulnerable workplaces within the Pokhara city of Nepal.

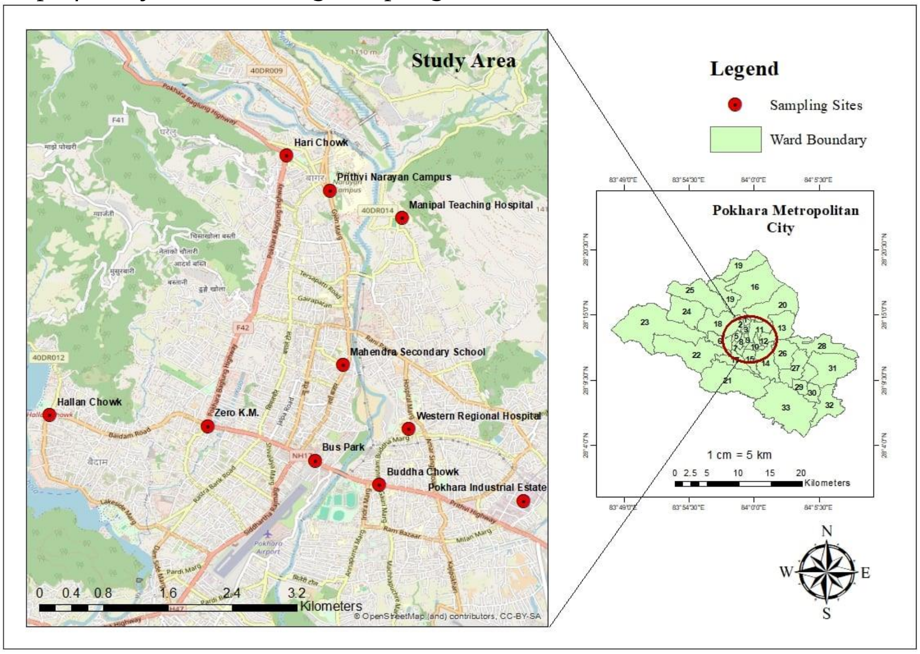
MATERIALS AND METHODS

Study Area

Pokhara is a historical, bowl-shaped city known for its ample scenic views of ice-capped mountains, green hills and lakes. Geographically, it is located between the latitudes of 27.55° to 27.83° N, and longitudes of 84.16° to 84.53° E in the central Nepal at the foothills of Mount Annapurna (Figure 1). Pokhara is the headquarters of Gandaki Province, and a famous tourist destination covers an area of 467.44 m^2. According to the census 2021, it has a population of 518,452, living in 101,669 households. The elevation ranges from the lowest of 505 m at Kotre to the highest of 2650 m at Armala above the sea level. The temperature in Pokhara varies from a low of 7°C in winter to a highest record of 38.5°C in summer, and it has the highest rainfall in Nepal, reaching up to 3800 mm annually (Devkota et al., 2023; Rai et al., 2020; Raut et al., 2020; Tripathee et al., 2016).

Figure 1

Map of Study Area Showing Sampling Sites



Study Method

A mixed method of qualitative and quantitative method of data collection was adopted in this study. A set of structured questionnaire survey was accomplished on focused workers to get their job status, perception to air pollution, safety measures, and health risks in the outdoor workspaces. The air quality data of the study season was assessed from the Department of Hydrology and Meteorology (DHM) of Nepal and *in-situ* measurement was made by the Smiledrive Air Quality Pollution Meter. The data were analyzed and compared to the WHO standard by using appropriate statistical tools. Graphical analysis was made using GNU Plot, and Excel 2016.

RESULTS AND DISCUSSION

Level of Particulate Matter during Pre-monsoon Season

The level of $PM_{2.5}$ and PM_{10} in the study area was found to be much higher than the safe level ($PM_{2.5}$, 50 µg/m³ and 100 µg/m³ for PM_{10}) in the Pokhara city during the study period of 2024, pre-monsoon as can be seen in Figure 2. The color code represents the level of health concern. The green color of AQ index from 0-50 µg/m³ represents safe level of air pollution, yellow color of 51-100 µg/m³ represents moderate level, orange color of 101-150 µg/m³ represents unhealthy for sensitive group, red color of 151-200 µg/m³ represents unhealthy, purple color of 201-300 µg/m³ represents very unhealthy, maroon color of 301-400 represents very hazardous, and maroon color of 401-500 µg/m³ represents very hazardous. The AQ index during pre-monsoon shows the unhealthy level of air pollution in the Pokhara city. Table 1 shows the details of air quality guidelines (AQG) for safe levels of air quality recommended by WHO, 2021.

Table 1

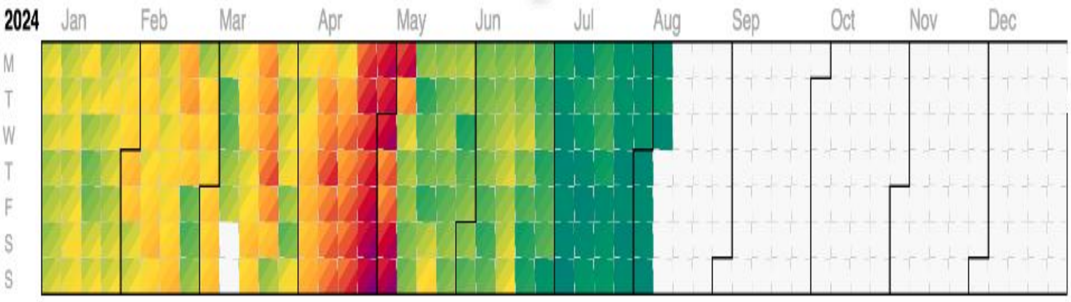
Safe Level of Air Quality According to AQG, WHO, 2021

Pollutant	Average time	Interim target 1	2	3	4	AQG level
$PM_{2.5}$	Annual	35	25	15	10	5
µg/m³	24-hour	75	50	37.5	25	15
PM_{10}	Annual	70	50	30	25	15
µg/m³	24- hour	150	100	75	50	45

(Source: https://www.ncbi.nlm.nih.gov/books/NBK574582/table/fm-ch1.tab)

Figure 2

Monthly Variation of $PM_{2.5}$ during January 1(Julian day 1) to August 7 (Julian day 217), 2024, Using the Color Index to Show the Pattern of Air Pollution Level in Pokhara. (Data Source: https://aqicn.org/data-platform/register/retrieved on 12:02, 2024/09/20)



The plot of daily variation of $PM_{2.5}$ and PM_{10} is shown in Figure 3. It shows the declining trend of both the $PM_{2.5}$ and PM_{10} from pre-monsoon to monsoon season with the equation of trend line,

$y = -0.2602x + 98.554$ for $PM_{2.5}$ and

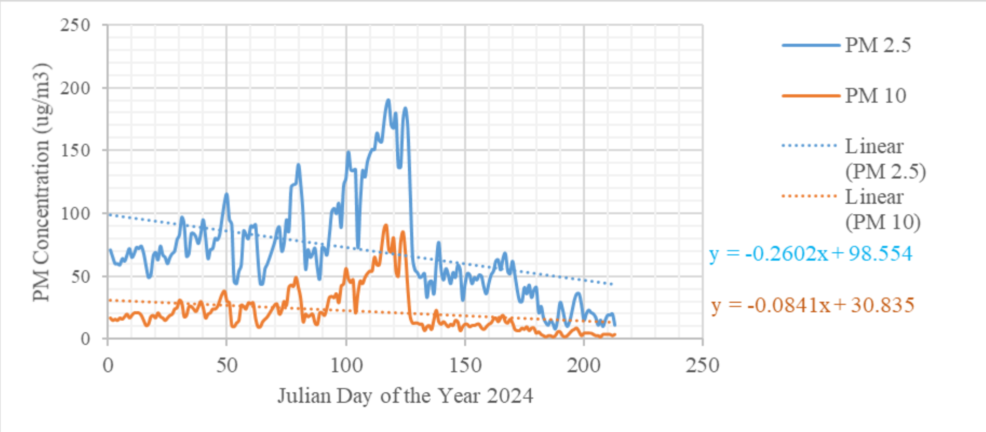
$y = -0.0841x + 30.835$ for PM_{10}

Here we can see, the average value of $PM_{2.5}$ is 98.55 µg/m³ and that of PM_{10} is 30.83 µg/m³. It means the concentration of fine mode particles is much greater than coarse mode particle. The month of April shows the highest peaks of both types of particles and PM $_{2.5}$ reaches up to 190 µg/m³. Since the fine particulate matter with a diameter less than 2.5 µm, can penetrate deep into the respiratory system, leading to severe health complications, the higher concentration of PM $_{2.5}$ in the city is a crucial threat to the working people exposed in such conditions.

A survey measurement of particulate matter concentration was conducted at the sampling sites on 27 April, 2024 during vehicle peak hours between 8:45 am to 4:45 pm. The data was recorded in each sampling site for 15 minutes using Smiledrive Indoor / Outdoor Portable Air Quality Pollution Meter. It shows the average value of $PM_{2.5}$ is 201.4 and that of PM_{10} is 98.3. For the same day, the average value of $PM_{2.5}$ over Pokhara city was 190 and that of PM_{10} was 71.

Figure 3

Daily Variation of $PM_{2.5}$ and PM_{10} during January 1 to August 7 (Julian day 217), 2024, Using the data from DHM, Pokhara. In situ Measurement of Particulate Matter Concentration at the Sampling Sites Using Low-cost Sensor



Clearly, the sampling sites were found to be more polluted than the overall city. Sampling sites along highways and in high-traffic areas, such as A1, A2, A3, and A7, showed higher concentrations of particulate matter compared to the core city areas (Table 2). Factors like the movement of heavy vehicles, construction materials used in highway repairs, and the direction of air flow likely contributed to the increased particulate matter levels.

Table 2

Sampling Sites of the Study

	April 27, 2024			
Location	Symbol	Time (Local)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)
Industrial area gate	A1	9:30 AM	217	115
Buddha Chowk	A2	9:15 AM	223	107
Prithvi Chowk	A3	9:00 AM	214	117
Naya Bazar	A4	8:45 AM	198	86
Zero km	A5	4:30 PM	193	95
Hallan Chowk	A6	4:45 PM	189	85

Hari Chowk	A7	4:00 PM	225	131
PNC, Bagar	A8	11:00 AM	178	82
Manipal Hospital	A9	10:30 AM	186	88
Western Regional Hospital	A10	10:15 AM	191	77
Average Value			201.4	98.3

Work Experience and Level of Job Satisfaction

In this study, work experience and the level of job satisfaction was assessed. On the basis of structured questionnaire, the respondents gave the mixed reports. We evaluated the job experience within three categories. People working for more than 10 years are found in very low percentages of 25.67±5.13% in indoors and 34.33±4.04% in outdoors and highest number of indoor workers (65±5) quit their job within five years (Table 3).

Table 3

Job Experiences of Indoor and Outdoor Workers in Pokhara

S. No.	Job type	1-5 years (%)	5-10 year (%)	More than 10 years (%)
1	Indoor workers	65±5	55±5	25.67±5.13
2	Outdoor workers	32.67±2.52	31.67±1.53	34.33±4.04

Note: Values are Mean ± SD, n=3

Most respondents were working due to family pressures and a lack of employment opportunities in safer environments. For outdoor jobs, such as traffic police, waste management, and media employees were routinely exchanged into dusty areas by their organizations, and after completing their shifts, they were replaced by other staff members. In the private sector, employees were often forced to either work in the prescribed sector or resign by the authorities. The level of job satisfaction was also evaluated where the indoor workers (29%) were found more satisfied to their jobs in comparison to the outdoor workers (17.67%) as shown in Figure 4.

Figure 4

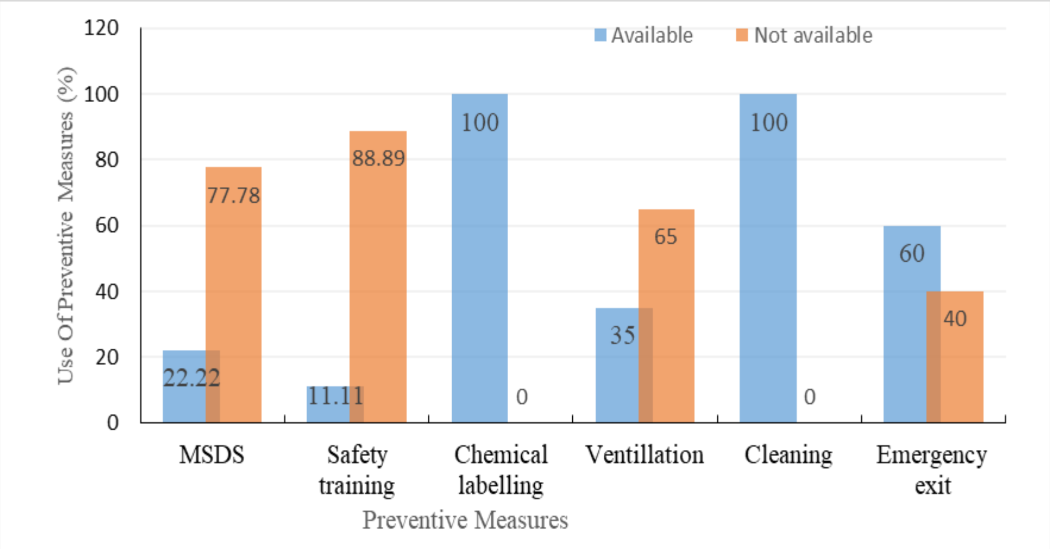
Level of Job Satisfaction of Indoor and Outdoor Workers in Pokhara

Precautionary Practice

The occupational safety and health of workers in hazardous sections need precautionary measures and robust safety and emergency systems. Long term exposure to particulate matter, UV radiation, ozone, SOx, NOx, polycyclic aromatic hydrocarbons, aldehydes and volatile organic compounds, zoonotic vectors etc. bring several health complications to the workers (Schulte et al., 2023). In this study, we focused on the precautionary measures adopted by the authorities for chemical risk, fire, explosion, cuts etc. in the working places. Most of the service providers were found unware about their potential risks and safety measures. In formal sectors like traffics, pharmaceutical and academic labs, municipal waste management cells, etc., authorities were literate about the terms and conditions but did implement the precautionary safety measures for their workers. Chemical labelling, safety cabinets and instructions, ventilation, proper waste management system, drinking water and lunch places were not managed properly. Employees were engaged haphazardly in the dusty and polluted work places. The material safety data sheet (MSDS) is an authorized document that provides information regarding potential hazards associated to a particular chemical. It is essential for the employees to be attentive of its impact on health, safety, emergency response, disposal and environmental influence (Eastlake et al., 2012). In this study, a low percentage (22.22%) of the job providers were known about its use. Very few workers (11.11%) had the safety training, all of the chemicals were found well labelled in the stock. About 35% of the workplaces were regularly cleaned once in a day and the waste was managed by the municipality. The working slots were poorly ventilated and only 60% of the workplaces were provided with adequate emergency exodus and rescue arrangement (Figure 5). Compared to government and well-established organizations, workers in informal and private sectors are found more vulnerable to air pollution, risk of chemical accidents, and health issues.

Figure 5

Use of Preventive Measures by the Workers of Different Sectors in Their Workplaces

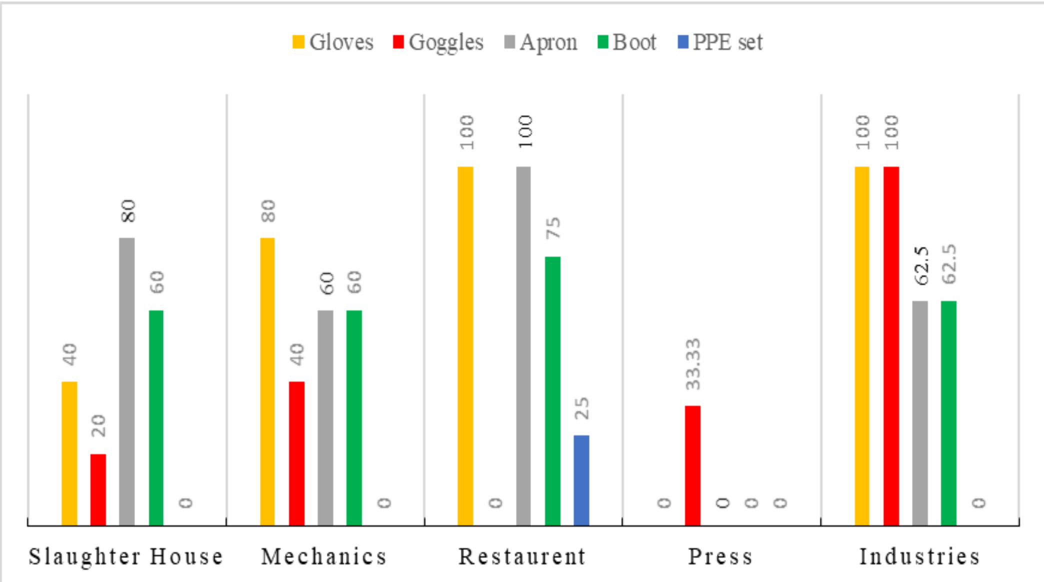


Personal Safety

The Occupational Safety and Health Administration (OSHA) advises that all workers in hazardous industries should be provided with comprehensive health and safety measures in their workplaces (OSHA, 2023). In this work, we conducted an extended survey to assess the use of proper safety measures by the workers engaged in outdoor and indoor polluted environment. The survey investigated the use of face masks, gloves, goggles, aprons, boots, and personal protective equipment (PPE) at their workplaces and the results are displayed in the bar diagram. All of the investigated organizations provided adequate sets of face masks and sanitizer to all of their employees. Employees were provided with necessary safety measures based on the nature of works and the working situations. Our results in Figure 5 shows that all workers in industries, restaurants, waste management, medical labs, and traffic police were provided with gloves. However, gloves were not used by the workers in printing presses. The findings reveal that glove practice was 62.5% in academic labs, 40% in slaughterhouses, and 80% among mechanical workers. All the workers of industries, medical labs and traffic police used goggles for the safety of their eyes but the restaurant workers were not observed using it. Goggles usage was reported by 20% of slaughterhouse workers, 40% of mechanics, 33.33% of printing press workers, 66.67% of the waste management personals, and 37.5% of academic lab technicians. In this survey, all the restaurant cooks, waste management staff, and medical lab technician used aprons, while traffic police and press workers did not. Similarly, 80% of slaughter house and meat shop workers, 62.5% of industry workers, 60% of mechanics, and 50% of academic lab workers used aprons during their works.

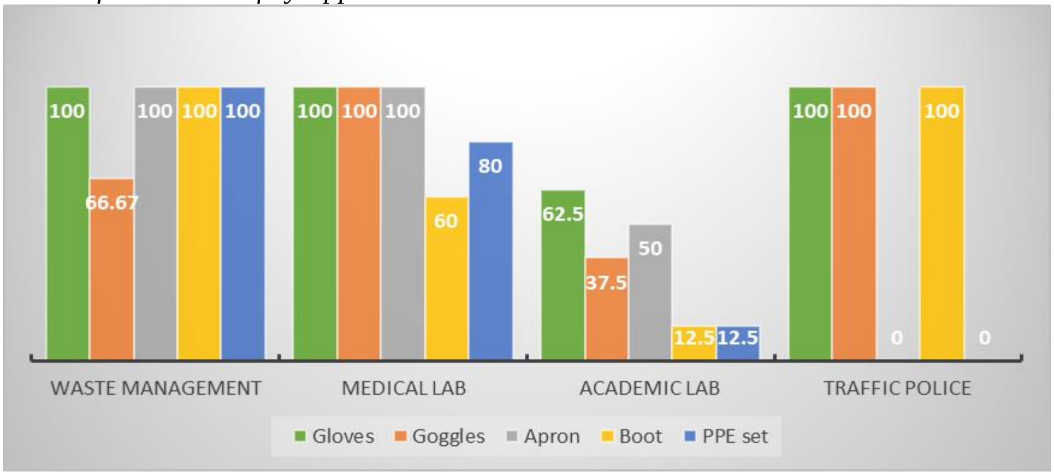
Figure 6

Status of Essential Safety Apparatus Provided to the Workers



They were given aprons by the management but wore them when they felt it was categorically urgent. Safety boots were worn by all personnel in waste management and traffic police, 75% of restaurant cooks, 62.5% of industry workers, 60% of those in slaughterhouses, mechanics, and medical labs, and 12.5% of academic lab workers (Figure 6, and 7).

Figure 7
Status of Essential Safety Apparatus Provided to the Workers

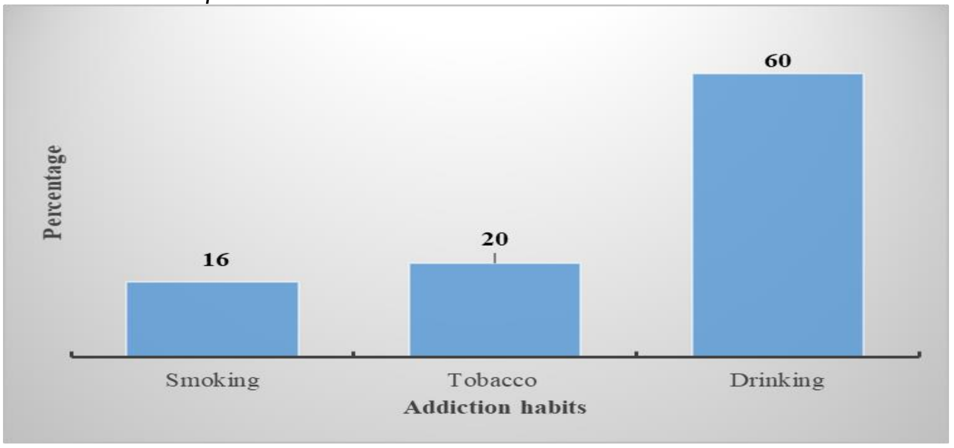


Printing press workers did not use safety boots. Personal protective equipment (PPE) was available to workers in waste management and medical labs, but it was typically used only when considered necessary. Following the COVID-19 pandemic, PPE practice surged, and employers guaranteed its availability for their workers. However, its use declined once the situation stabilized.

Health Complications, Insurance and Treatment Facility

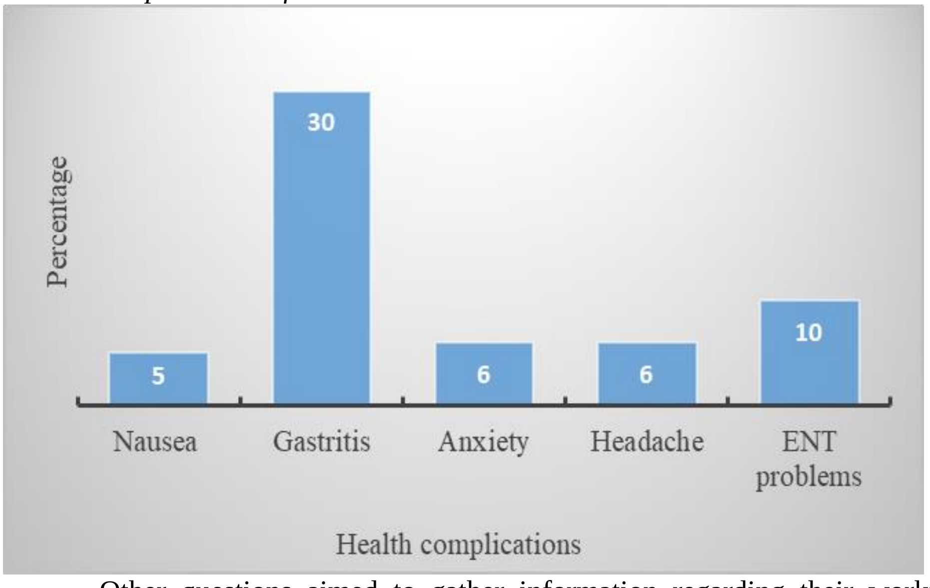
Exposure to polluted air in the workplace significantly impacts workers' health. Numerous studies have indicated that a lack of awareness, poverty, negligence, and strict regulatory systems are key factors contributing to occupational health risks for laborers (Balkhyour et al., 2019). Health status, emergency managements, insurance and treatment facility provided to the indoor and outdoor workers of Pokhara was assessed. A pre-designed script was used to assess the health issues, harmful lifestyle habits, insurance coverage, and medical facilities available to the workers. After gaining verbal consent, each worker was interviewed at their workplace, with responses recorded in a logbook for data analysis. The questions focused on their habits, such as alcohol consumption, smoking, or tobacco use, as well as their health history and current health conditions and the results are shown in Figure 8. The study revealed that 60%, 20%, and 16% of individuals had behaviors of alcohol consumption, chewing tobacco, smoking, or a combination of all three. Although they know the harmful effects of these conducts, they credited their addiction to the influence of their peers and social environment.

Figure 8
Bad Addictions of the Workers



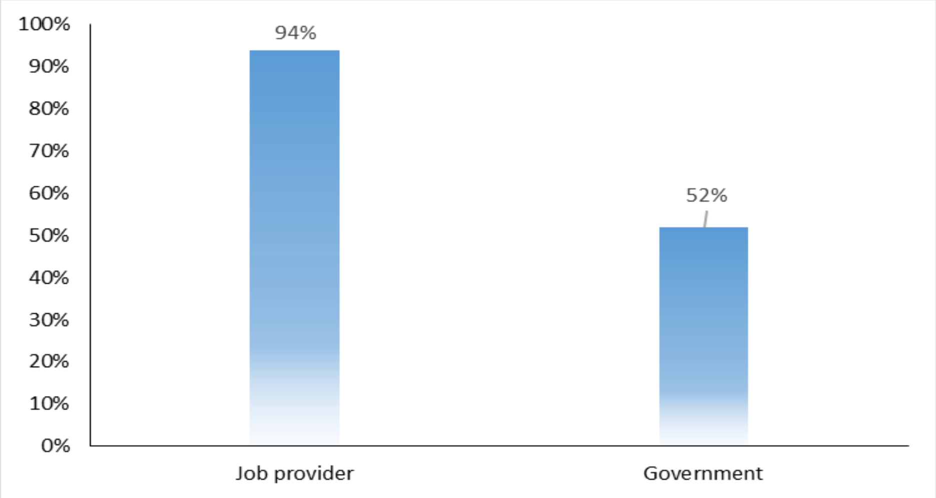
In this study, participants were asked about their health issues (Figure 9). The most commonly reported condition was gastritis (30%), followed by ENT problems (10%), headaches (6%), anxiety (6%), and nausea (5%). The workers were ignorant whether their health issues were pre-existing or worsened by exposure to polluted air. Most of the employees were the males between the ages of 20 to 40, and many be likely to force to leave/ leave their jobs once their health conditions became severe.

Figure 9
Health Complications of the Workers



Other questions aimed to gather information regarding their working hours, access to emergency care, and health reimbursements. The results presented in Figure 3 indicate that only 52% of the participants received health insurance from the Government of Nepal, while 94% were provided with insurance by their employers' (Figure 10).

Figure 10
Medical Support Provided to the Workers



Identification and prevention of occupational health risks of the workers is important in saving national health cost and efficiency of the workers. Regular assessment of working conditions, implementation of proper safety measures, provision of health allowances, and routine medical checkups are fundamental rights of workers. In this study, we assessed only a few worksites in the Pokhara Valley during a single season. Further comprehensive studies on pollution levels and a collective effort to ensure a safe environment and public health are crucial for maintaining a sustainable social system in the nation.

CONCLUSION

The air inhaled by people working both indoors and outdoors is contaminated with various organic and inorganic pollutants that pose health risks. This study evaluated the levels of air pollution during the most polluted season (April) of the year by measuring $PM_{2.5}$ and PM_{10} concentrations. The study also examined the safety measures, health conditions, and facilities provided to workers in dusty areas, across both formal and informal sectors. Our findings emphasize that many workers are forced to work in unsafe environments due to a lack of awareness, negligence and rigorous policies. This research provides important insights into the health status and awareness of workers, particularly in informal, small, and self-employed sectors. It will be beneficial for both authorities and workers in updating and enhancing occupational health and safety measures in the workplace. Based on our observation, it is essential to implement multifaceted policy interventions aimed at reducing $PM_{2.5}$ emissions. For this, it is essential to aware citizens about severe adverse effects of air pollution, promoting public transportation, and investing in renewable energy sources. Public awareness about minimizing exposure and advocating for community-level action against pollution may help improving the air quality. By prioritizing these strategies, Pokhara can foster a healthier urban environment, ultimately protecting the well-being of its population and ensuring sustainable urban development.

AUTHOR CONTRIBUTIONS

***JR**: Conceptualization, Data acquisition, Software, Writing original draft and review. **LNK**: Conceptualization, Data acquisition, Software, Writing original draft and review. **RP**: Data collection, analysis and review, **RKB**: Data collection, analysis and review. **JBM**: Data analysis and computer work. **SA**: Review and Editing.*

CONFLICT OF INTERESTS

The authors show no conflict of interests on this work.

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